Sharad Y. Shastry
Prepared by

Charles H. Moser
Approved by

1.0 INTRODUCTION

The goal of supply and distribution planning is to provide adequate capacity for each element of the electrical system and to ensure reliable service to the customer on an economic basis. The objective is the optimum use of capital while maintaining acceptable standards of service[1]. This guide has been prepared to help planning engineers consistently meet this objective.

This guide applies to National Grid Companies' local area supply and distribution facilities (below 69 kV) which are not a critical portion of the interconnected bulk transmission network and do not connect major generation to the transmission network. In the latter cases, planning guidance is provided by the New England Power (NEP) Transmission Planning Guide[2], which establishes minimum requirements for transmission system reliability, and which does not necessarily apply to area supply problems.

Since many area plans may directly affect the interconnected system, the Transmission provider (NEP) has complete responsibility for ensuring that regional Transmission planning criteria are not violated; National Grid Retail Companies provide the load and interconnection information to facilitate the required Transmission interconnection and adequacy studies.

2.0 SUPPLY AND DISTRIBUTION DESIGN CRITERIA

The design of supply and distribution facilities should preclude equipment loadings above emergency capabilities, and voltage regulation beyond acceptable limits, which could otherwise cause damage to our own or customers' equipment.

The following sections list several basic criteria that will guide the analysis and design of the supply and distribution system.

2.1 <u>Load Forecasts</u>

The Power Supply Area (PSA) load forecast is updated annually[3]. The PSA is the smallest unit for which forecasts are developed. Further apportioning of the PSA load if required, is done proportionally to the coincident peak demands of areas within the PSA by the planning engineers.

After area plans are developed, their economic sensitivity to change in load growth is tested. The results of this testing are included in the study report.

2.2 <u>Thermal Capabilities of Equipment</u>

Thermal limits must be recognized for all system elements in conducting planning studies. Thermal capabilities are determined so that maximum use can be made of all equipment. Several factors are taken into account, including ambient temperatures, load cycles, wind velocities, and potential loss of life of equipment.

Definitions of thermal capabilities of various system elements are provided in the following sections.

2.2.1 Overhead Conductors[4,5,6]

The current carrying capacity (ampacity) of an overhead conductor may be limited either by conductor clearances or maximum allowable operating temperature under a predefined set of reasonably severe Summer or Winter ambient conditions.

The sag of a conductor increases due to elastic elongation as its temperature increases. If the operating time at elevated temperatures is long enough, inelastic elongation (creep) occurs. Both effects must be considered to determine sag limitations on the conductor ampacity. Elevated temperature operation also increases the loss of tensile strength of the conductor, thus reducing its life.

The maximum ampacity of an overhead conductor is estimated for Normal (continuous), Long-Time Emergency (LTE), Short-Time Emergency (STE), and Drastic Action Limit (DAL) operations for summer and winter conditions. Other short duration ratings, if required for maintenance or construction, are estimated conservatively using seasonal ambient data along with circuit specific information.

2.2.2 Underground Cables[7]

Ampacities are defined for underground cables as follows:

Normal Ampacity

This is the maximum loading on the cable that does not cause the conductor temperature to exceed its design value at any time during a 24-hour load cycle.

One-Hour to 24-Hour Emergency Ampacities

These are the maximum emergency loadings on the cable that do not cause the conductor temperature to exceed its allowable emergency value at any time during the period. At the end of the emergency time period, the load on the cable must be reduced so that the peak load in the next load cycle does not exceed the 100-hour ampacity (defined below). The length of the emergency time period refers to the total duration of the emergency loading, not to the duration of the peak on the normal load cycle.

100-300 Hour Ampacity

This is the maximum emergency loading on the cable that does not cause the conductor temperature to exceed its applicable emergency value over a period of several consecutive 24-hour load cycles. At the end of the emergency time period, the load on the cable must be reduced to a value within its normal ampacity.

2.2.3 Transformers[8,9,10]

Thermal capabilities of transformers are based on IEEE Guide for Loading Oil-Immersed Power Transformers for up to 100 MVA (C57.92-1981) and in excess of 100 MVA (C57.115-1991). Three categories of transformer capabilities are defined below:

Normal Capability

Winter normal and summer normal capabilities are based on a normal daily load cycle, and on the maximum 24-hour average ambient temperature for the period involved. Loading at these levels does not result in significant reduction of expected life on the transformer.

Short-Time Emergency Capability (1/2 hour or less)

A negligible loss of life is incurred if the transformer load is limited to twice nameplate rating for 30 minutes or less.

Long-Time Emergency Capabilities (1 hour to several days)

These capabilities are based on a normal daily load cycle, with the emergency load increment added. The maximum 24-hour average ambient temperature is used for the appropriate season. A cumulative loss of life may be accepted under these conditions so long as the maximum allowable top oil temperature or hot spot temperature in the winding are not exceeded. A 5% loss of life per event and an average of 2-1/2 percent loss of life per year may be allowed for emergency loading conditions only, as long as the maximum allowable top oil temperature or the hot spot winding temperature are not exceeded.

2.2.4 Other Equipment[4,5,6]

Normal and emergency capabilities of all other series equipment must be calculated and considered. Emergency capabilities usually involve elevated temperatures with some potential loss of equipment life.

However, any circuit rating may be limited by other circuit equipment such as circuit breakers, disconnects, etc. or even current transformers at the two terminals of the circuit. These ratings are generally based on the allowable maximum temperature of the equipment.

2.3 Application of Equipment Capabilities

In the application of thermal capabilities, it is assumed that load relief is attained by automatic or manual switching, generation adjustments, or other means, within allowable time limits.

Normal Equipment Capabilities Must Not Be Exceeded

N For normal operating conditions

N For the loss of a transformer where a mobile unit cannot be utilized.

N For the loss of generation on which area supply and distribution is dependent.

Emergency Equipment Capabilities Must Not Be Exceeded As Follows:

N For the loss of an overhead line, do not exceed:

a. The 1 hour to 24 hour emergency ampacity of underground cable circuits;

b. The long-time emergency capability of transformers;

c. The long-time emergency ampacity of overhead circuits;

d. The long-time emergency capability of auxiliary equipment.

N For the loss of a transformer where a mobile unit can be utilized, or for the loss of a cable operating at less than 115 kV in a duct bank, do not exceed:

a. The 24-hour emergency ampacity of underground cable circuits;

b. The long-time emergency capability of transformers;

c. The long-time emergency ampacity of overhead circuits;

d. The long-time emergency capability of auxiliary equipment.

N For the Loss of a Direct Buried or Submarine Cable Rated at Less Than 115 kV, or a 115 kV Cable in Duct, do not exceed:

a. The 100-hour emergency ampacity of underground cables;

b. The long-time emergency capability of transformers;

c. The long-time emergency ampacity of overhead circuits;

d. The long-time emergency capability of auxiliary equipment.

N For the Loss of 115 kV (and above) Direct Buried, Submarine, or Pipe Type Cables, do not exceed:

a. The 300-hour emergency ampacity of underground cables;

b. The long-time emergency capability of transformers, taking into account duration of outage and available methods of load relief;

c. The long-time emergency ampacity of overhead circuit;

d. The long-time emergency capability of auxiliary equipment.

2.4 Voltage Regulation

The ultimate goal is to keep all customers' service voltages within accepted limits. From a supply point of view, the acceptability of voltage regulation is determined at the distribution substation buses. At substations with feeder or bus regulating equipment, the regulation (the extreme range of voltages expressed as a percentage of normal peak load voltage) should be no greater than 10 percent for normal and 15 percent for emergency conditions on the source side of the regulating equipment. Most substation regulating equipment has a range of 20 percent. Under normal conditions, therefore, half the regulator range can compensate for variations in supply voltage, leaving the other half available for voltage drops on the distribution feeders. The substation transformer taps should be chosen to allow this control.

The voltage regulation at substation busses without regulating equipment should be within 5 percent for normal and 10 percent for emergency conditions.

2.5 Service Reliability

The supply and the distribution systems in the National Grid Companies are designed to limit the interruption of energy (MWh) delivery for a loss of any single element.

In planning the development of the system, it is recognized that some highly improbable events involving loss of more than one element, such as multiple and common mode outages, may occur resulting in a much larger interruption of energy delivered.

The indices of service reliability are the annual frequency of customer interruption (f) and the average duration of interruption (Di). The product of these two indices is the average annual duration of interruption per customer served (Ds). Since the total system is involved in supplying the customer, ensuring an acceptable reliability of service to all customers requires designing the supply and the distribution systems in an integrated manner to limit the interruption of energy delivery.

The design criteria report[1] establishes the criteria for designing the system to ensure an acceptable reliability of service for all National Grid Companies' customers. The applicable guide[11] illustrates the reliability evaluation techniques.

2.5.1 Distribution Design Criteria

For system design, transmission lines (69 kV and above) and the associated substation transformers should be considered as part of the supply system. The subtransmission lines (below 69 kV) and the distribution feeders, which are similar in construction to each other and have a higher outage rate compared to transmission lines, should be considered as part of the distribution system.

The design criteria, reformulated to maintain the current service reliability for National Grid Companies, are as follows:

Supply Design Criterion (SDC):

The supply system should be designed to limit the interruption caused by an outage of a single supply line or substation element to 480 MWh, based upon peak load.

Feeder Design Criterion (FDC):

The distribution system should be designed to limit the interruption caused by an outage of a single distribution feeder to 20 MWh, based upon peak load.

Duration Design Criterion (DDC):

The supply and the distribution systems should be designed so that the five-year average annual duration of interruption per customer served (Ds) on a feeder basis, excluding severe weather related events, does not exceed 200 minutes per year

2.5.2 Multiple Outages

? Simultaneous outage of both circuits on overhead double circuit structures may result in the loss of an entire area load. Since these outages are nearly always due to faults caused by lightning, it is reasonable to assume that both circuits will not be permanently faulted, and that at lease one circuit can be restored to service quickly by a successful reclosure. The effect on the rest of the interconnected system must be evaluated, however, even for temporary simultaneous outages.

? Planning for supply to secondary underground networks could consider the consequences of overlapping outages on the supply cables.

? The loss of two transformers should be considered at locations where a mobile or spare transformer is not available or does not have sufficient capability to carry the entire load, and then only with the concept that the second transformer may fail while the first unit is being repaired. The interruption should be limited to 480 MWh, after allowing for load transfers.

? The outage of a local generating unit or supply facility while one generator is already out due to failure or maintenance, should not result in loss of load. It is reasonable to interrupt 480 MWh or less if a third generating unit is forced out of service.

? The probability of independent, overlapping outages of two underground cables or two overhead supply circuits is extremely low. For this reason, facilities should not be planned to protect against this condition. In some cases, it may be advisable to evaluate the consequences.

2.5.3 Common Mode Events

Some single events on the system may result in the outage of more than one element. Examples include loss of the common oil supply to parallel pipe-type cables, a dig-in to closely spaced cables in a common duct bank or trench, or loss of a common cooling system to multiple substation transformers.

These occurrences are sufficiently rare so that firm capability need not be provided to protect against them. However, no load should be interrupted for more than 24 hours by such an event. Shorter outages may be indicated by the nature of the load interrupted.

2.5.4 Maintenance of Facilities

Although maintenance is usually performed at off-peak periods, an outage of an element (other than a generator) while another element is out for maintenance may result in some loss of load. The system should be designed, however, such that loss of an entire major urban load center or other large block of load for greater than a few hours does not occur following such an event.

2.5.5 Operation During Construction

Some of these guidelines may need to be relaxed during construction in order to accomplish the work. Each situation should be reviewed individually. As a guide, however, the possible loss of an entire major urban load center or other large block of load for several hours following a single contingency should be avoided. The risk should be weighed in terms of customer sensitivity, a season of year, weather forecasts, and other relevant factors.

2.6 Sizing of New Facilities

All equipment should be sized based on economics and operating requirements. Spreadsheet computer programs can be readily created and used to determine the economic size of conductors and transformers based on total owning costs.

2.7 System Stability

Consideration must be given to system stability if major transmission and substation facilities are altered to accommodate the supply circuits. The supply system must then comply with the stability requirements for the interconnected power system as specified in the Transmission Planning Guide[2].

2.8 Other Major Considerations

The planning engineer must consider the effect of each plan on all aspects of system design. These include:

? Short Circuit Duty

? Protection

? Operation and Maintenance

? Transmission Planning

3.0 ECONOMICS[12]

Engineering economics should be used to compare all plans on a common basis. Annual charges on investments, losses, rentals, and all other expenses should be determined for each plan.

The cumulative present worth of annual revenue requirement through the end of the study period for each plan provides one input for comparing plans.

If the plan with the lowest long-range cost has a higher initial investment than one or more of the others, a year-by-year analysis should be made for the first few years.

Some studies involve investments proposed to reduce or eliminate an annual expense. In these cases, a year-by-year analysis must justify the investment alternative.

4.0 REPORTS AND REVIEWS

A supply and distribution study should culminate in a concise report describing the assumptions, procedures, economic comparison, conclusions, and recommendations resulting from the study. Reviews of area planning studies should be made when condition changes justify them. Justification for review of a study might include a new load forecast, change in load distribution, major new loads, availability of new line routes, loss of a proposed route, or other condition changes. Area planning studies should be reviewed periodically to permit adequate overlap in the study periods.

5.0 REFERENCES

1. Report: "Reformulated Distribution Design Criteria", by V. D. Antoniello, S. Y. Shastry, R. D. Sheridan and R. G. Wheeler, dated November, 1997.

2. Procedure No: NEP – 1.0 titled "Transmission Planning Guide", approved by Dana Walters, issued on November 17, 1977 or later version.

3. Report: "New England Electric System Retail Companies 1998 PSA Forecast", by Regional Economic Research Inc. or latest version.

4. Capacity Rating Procedure By The System Design Task Force of the NEPOOL Planning Committee, dated October 1990.

5. Reliability Standards in The New England Power Pool, dated April 1991.

6. National Grid Companies' Computer Programs 65 (Circuits), 92 (OH Conductor Normal Capabilities) and 108 (OH Conductor Emergency Capabilities).

7. National Grid Companies' Computer Programs 10 and 20 (UG Cable Ampacities).

8. IEEE C57.92-1981 (Reaff. 1991), Guide for Loading Mineral-Oil-Immersed Power Transformers Up To and Including 100 MVA with 55°C and 65°C Average Winding Rise.

9. IEEE C57.115-1991 (Redesignation of IEEE Std. 756, Trial Use May 1984), Guide for Loading Mineral-Oil-Immersed Power Transformers Rated in Excess of 100 MVA (65°C Winding Rise).

10. National Grid Companies Computer Programs 4, 156, 157 and 158 (Transformer Capabilities).

11. The "Guide for the Application of Distribution Design Criteria", by S. Y. Shastry and J. M. Thompson.

12. Memo: "Revenue Requirements Factors, and Cost of Losses Update", to C. H. Moser by D. K. Pantalone, dated September 20, 1996 or latest version.